

**PCT**WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau

## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>7</sup> :</b> <b>F02B 11/00, F01L 9/04, F02D 41/04, 43/00</b>	<b>A1</b>	<b>(11) International Publication Number:</b> <b>WO 00/28197</b> <b>(43) International Publication Date:</b> 18 May 2000 (18.05.00)
<b>(21) International Application Number:</b> PCT/SE99/01928 <b>(22) International Filing Date:</b> 26 October 1999 (26.10.99)  <b>(30) Priority Data:</b> 9803667-6                      26 October 1998 (26.10.98)                      SE  <b>(71) Applicant (for all designated States except US):</b> AB VOLVO [SE/SE]; S-405 08 Gothenburg (SE).  <b>(72) Inventor; and</b> <b>(75) Inventor/Applicant (for US only):</b> DENBRATT, Ingemar [SE/SE]; Bofinksvägen 3, S-429 33 Kullavik (SE).  <b>(74) Agents:</b> BERG, S., A. et al.; Albihns Patentbyrå Stockholm AB, P.O. Box 5581, S-114 85 Stockholm (SE).		<b>(81) Designated States:</b> JP, KR, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.</i> <i>In English translation (filed in Swedish).</i>
<b>(54) Title:</b> METHOD OF CONTROLLING THE PROCESS OF COMBUSTION IN AN INTERNAL COMBUSTION ENGINE, AND ENGINE WITH MEANS FOR CONTROLLING THE ENGINE VALVES  <b>(57) Abstract</b>  Four-stroke internal combustion engine with electrically operated inlet and exhaust valves (9, 11) and means for supplying a homogeneous fuel/air mixture to the engine cylinders (1). The valves are controlled by a control unit (15), which, within a lower rpm range, closes the exhaust valve (11) before the piston (4) has reached its upper dead center point. Under the effect of trapped residual gas, a temperature increase is achieved, which results in compression ignition of the fuel/air mixture. The control unit (15) controls the exhaust valve (11), so that the amount of residual gases in the cylinders at the closing of the exhaust valves is greater at low loads and high rpm than at high loads and low rpm, in order to control the ignition delay in this manner.		

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LJ	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

Method of Controlling the Process of Combustion in an Internal Combustion Engine, and Engine with Means for Controlling the Engine Valves.

- 5 The present invention relates to a method of controlling the combustion process in the combustion chamber in a four-stroke internal combustion engine with at least one cylinder having at least one inlet valve and at least one exhaust valve, comprising supply of a homogeneous fuel/air mixture to the combustion chamber and compression of the mixture to self-ignition.
- 10 The invention also relates to a four-stroke internal combustion engine with at least one cylinder having at least one inlet valve and one exhaust valve, means for supplying a homogeneous fuel/air mixture to the cylinder combustion chamber and control means for at least varying the degree of opening of the exhaust valve.
- 15 In compression ignition of a homogeneous fuel/air mixture, so-called HCCI (Homogeneous Charge Compression Ignition) in a four-stroke internal combustion engine, a homogeneous diluted (with extra air or residual gas) fuel/air mixture is compressed to self-ignition. The advantage of this compared to first compressing the inlet air and then injecting fuel into the combustion chamber (the diesel process) is that the
- 20 entire fuel/air mixture burns simultaneously and not successively as when a flame front propagates through the combustion chamber from a sparkplug or injector. This creates a homogeneous temperature in the combustion chamber, which in turn makes it possible to achieve, for example in an unthrottled Otto-engine at partial load, the efficiency of the diesel engine but without the high nitrogen oxide and particle emissions of the diesel engine. The nitrogen emissions can be reduced from ca.
- 25 1000 ppm to as little as 10-20 ppm. The particle emissions of the diesel engine can be reduced to the same level as those of the Otto-engine. The difficulty is, however, to control the combustion since it is kinetically controlled. If the mixture is too rich, the energy released will be too rapid (knocking), and if it is too lean, ignition will be
- 30 made impossible. In an HCCI Otto-engine with gasoline as fuel, a high and control-

led temperature is required to achieve self-ignition, and this can be achieved with high compression ratio and/or by heating the inlet air. In an HCCI diesel engine with diesel oil as fuel, lower temperatures are required than with a normal diesel engine, which means that the compression ratio must be lowered.

5

The difficulty up to now in HCCI engines has been to control the ignition delay (the cylinder temperature) in such a manner that the combustion is positioned correctly about the top dead centre at various rpm:s and loads, and this has greatly reduced the range of use of such engines. Especially, control problems during transients, where the cylinder temperature must be checked from one cycle to the next, have limited the range of use of HCCI engines to generators, for example, where the drive unit operates with very small variations in rpm and load.

10

The purpose of the present invention is to achieve a method of controlling the temperature in the cylinders in an HCCI engine, so that the ignition time will be correct at various engine speeds and loads, thereby making it practically possible to use HCCI engines in motor vehicles, thereby reducing their fuel consumption and emissions.

15

This is achieved according to the invention by virtue of the fact that the exhaust valve during the exhaust stroke of the piston is controlled so that it, at least within a lower rpm range, closes before the piston has reached its upper dead center point, the degree of opening of the valve being varied, depending on engine load and rpm so that the amount of residual gas at closing of the valve is greater at low loads and high rpm than at high loads and low rpm, to thereby vary the ignition delay by varying the degree of dilution of the fuel/air mixture with residual gases in the combustion chamber.

20

25

Complete freedom of valve control, so that the opening and closing times can also be freely controlled from cycle to cycle, can be achieved by using electromagnetic-

30

ally operated valves. The amount of residual gases which determine the temperature in the combustion chamber and thus the ignition time, can be regulated in this manner within a broad interval, within which the temperature increases the earlier the exhaust valve is closed.

5

In order to prevent increase in engine pump work (pump losses), according to a further development of the method according to the invention, the inlet valve is so controlled during the inlet stroke of the piston, that, at least within said lower rpm range, it opens a certain number of crankshaft degrees after the upper dead center point of the piston, the degree of opening being varied relative to the degree of opening of the exhaust valve, to reduce residual gas pressure in the combustion chamber to the inlet air pressure.

An HCCI engine which must be able to operate within a wide rpm range, e.g. with an upper limit of about 6000 rpm, is preferably equipped with an ignition system which is controlled so that it is deactivated within said lower rpm range, the upper limit of which can lie between 3000 and 4000 rpm. When this limit is exceeded, the ignition system is activated at the same time as the control of the exhaust and inlet valves is changed to normal engine operation, i.e. the exhaust valve is controlled so that it closes after the piston, during the exhaust stroke, has reached its upper dead center, at the same time as the inlet valve is controlled so that it begins to open before the exhaust valve is completely closed. The same applies at high load and low rpm, since otherwise the rate of combustion will be too high as the degree of dilution is reduced.

25

An internal combustion engine of the type described by way of introduction, which is to be controlled in the above described manner, is characterized in that the control means are so arranged to control the exhaust valve during the exhaust stroke of the piston, that the valve, at least within a lower rpm range, closes before the piston has reached its upper dead center point, and that the degree of opening of the valve is

30

varied, depending on the engine load and rpm, so that the amount of residual gases in the combustion chamber at the closing of the valve is greater at lower loads and higher rpm than at higher loads and lower rpm.

5 The method according to the invention will be described below with reference to the accompanying drawings, where Figs. 1- 4 show schematically a cylinder with associated piston in a four-stroke internal combustion engine, and Figs. 5-7 show various valve control diagrams.

10 In Fig. 1, 1 designates a cylinder in the engine block of a four-stroke internal combustion engine, which in the example shown is an Otto-engine, having a sparkplug 2 projecting into the combustion chamber 3. The cylinder 1 has a piston 4, which is connected via a connecting rod 5 to a throw 6 on the crankshaft 7. The combustion chamber 3 has an inlet 8 for supply of fuel/air mixture. An inlet valve 9 is arranged  
15 in the inlet port of the combustion chamber. An exhaust valve (not shown) is arranged in an outlet port to the exhaust conduit.

The opening and closing of the inlet and exhaust valves 9 and 11 are electromagnetically controlled with the aid of electromagnetic devices 12 and 13, respectively.

20 The valves can be of a type which is known per se with a valve spindle, joined to a metal disc located between two electromagnets. The electromagnets are magnetized alternately and the metal disc is drawn towards that magnet which is momentarily magnetized. With electromagnetically controlled valves of this known type, the degree of opening of the valves can be freely controlled, both from cycle to cycle and  
25 for individual cylinders. The sparkplug 2 is joined to an ignition system 14 with a control unit, into which, i.a., signals representing engine rpm and accelerator pedal position are fed for controlling the ignition as a function of engine rpm and load. The electromagnets of the valves 9,11 are controlled by a control unit 15, into which there is fed a signal from a sensor (not shown), which directly or indirectly measures

the pressure P in the cylinder chamber, and/or a signal representing the ion flow. This signal can be obtained with the sparkplug as a sensor.

Figs. 1- 4 show HCCI operation, i.e. the ignition system is deactivated and ignition of the fuel/air mixture supplied to the combustion chamber 3 is effected by self-ignition during compression of the mixture. Fig. 1 illustrates the position EC of the plunger when the exhaust valve 11 closes during the exhaust stroke, at low load and high rpm within the low rpm range, i.e. up to ca. 3000 - 4000), while Fig. 2 shows the position IO of the piston when the inlet valve 9 opens during the inlet stroke under the same operating conditions. Figs. 3 and 4 show in a corresponding manner the piston position EC and IO at higher load and lower rpm. In Figs. 5-7, EO designates exhaust open, EC exhaust closed, IO inlet open and IC inlet closed. Fig. 5 shows the valve times at low load and high rpm while Fig. 6 shows the corresponding times at high load and low rpm. At a given load, rpm and ratio between air and fuel in the fuel/air mixture, a shorter ignition delay (earlier ignition start) is obtained the earlier the exhaust valve closes, because the amount of trapped hot residual gases will in this case increase in the combustion chamber. By feeding back the ion stream signal or the pressure sensor signal, the opening and closing of the valve can be regulated so that the combustion can be correctly positioned during HCCI operation within the entire lower rpm range.

When the rpm exceeds the upper limit of the lower rpm range, e.g. ca. 4000 rpm for a passenger car with a top end rpm of ca. 6000 - 8000 rpm, the valve control is switched to normal Otto-engine operation, i.e. with said valve overlap, as shown in Fig. 7, at the same time as the ignition system is activated. The same is true when the engine load exceeds 50-70% of the maximum engine load.

The degree of opening of the valves can in principle be regulated in two manners for controlling the amount of residual gas during the exhaust stroke or during the pressure reduction during the inlet stroke. Either the length of stroke of the valves can be

constant and the times for closing the exhaust valve and opening the inlet valve can be varied, as illustrated in Figs. 1-4, or the length of stroke of the valves can be varied and the opening time can be constant or they can be controlled with a combination of the two methods.

5

With an Otto-engine in HCCI operation, an efficiency can be obtained corresponding to that of a normal diesel engine, but without the particle emissions of the diesel engine. Even a diesel engine can be run in HCCI operation with corresponding control of the valves. Double fuel injectors are required in this case, however, viz.

10

firstly, injectors for injecting fuel into the inlet tube for HCCI operation within a lower rpm range, and, secondly, injectors for direct injection at normal diesel operation within the rpm range thereover. Furthermore, devices are required for switching the fuel injection.

15

Variable valve control can also be obtained with other means than electromagnets.



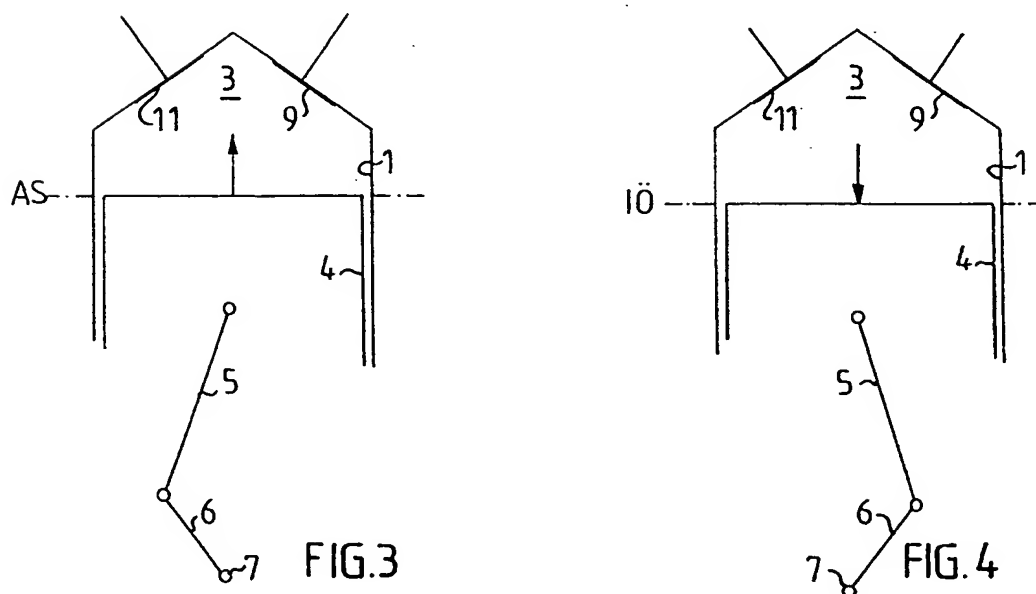
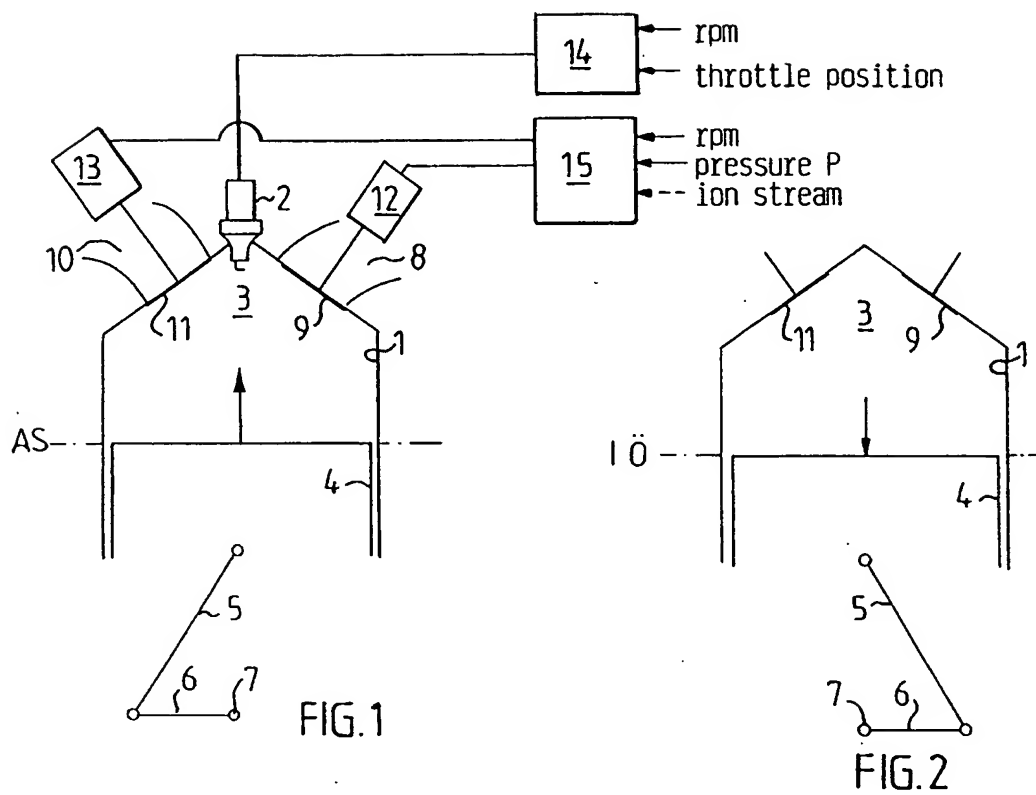
### Claims

1. Method of controlling the combustion process in the combustion chamber (3) of a four-stroke internal combustion engine with at least one cylinder (1) having at least one inlet valve (9) and one exhaust valve (11), comprising supply of a homogeneous fuel/ air mixture to the combustion chamber, and compression of the mixture to self-ignition, **characterized** in that the exhaust valve (11) during the exhaust stroke of the piston (4) is controlled so that it, at least within a lower rpm range, closes before the piston has reached its upper dead center point, the degree of opening of the valve being varied, depending on engine load and rpm so that the amount of residual gas at closing of the valve is greater at low loads and high rpm than at high loads and low rpm, to thereby vary the ignition delay by varying the degree of dilution of the fuel/air mixture with residual gases in the combustion chamber.
2. Method according to claim 1, **characterized** in that the inlet valve (9), during the inlet stroke of the piston (4), is controlled so that it, at least within said rpm range, opens a certain number of crankshaft degrees after the upper dead center point of the piston, the opening angle being varied in relation to the opening angle of the exhaust valve (11), to reduce the residual gas pressure in the combustion chamber (3) to the inlet pipe air pressure.
3. Method according to claim 1 or 2 for controlling the combustion process in an internal combustion engine with means (2) for spark ignition of the fuel/air mixture in the combustion chamber (3), **characterized** in that the spark ignition means (2) are kept deactivated within said lower rpm range and are activated when the engine rpm exceeds the upper limit of the lower rpm range, and that the exhaust valve (11) within the upper rpm range is controlled so that it closes after the piston (4), during the exhaust stroke, has reached its upper dead center point.

4. Method according to claims 2 and 3, **characterized** in that the exhaust valve (11) and the inlet valve (9) are controlled so that the inlet valve begins to open before the exhaust valve has completely closed.
5. Method according to one of claims 1- 4, **characterized** in that electromagnets (12,13) are used to control the valves (9,11).
6. Method according to one of claims 1-5, **characterized** in that gasoline is used as fuel.
7. Four-stroke internal combustion engine with at least one cylinder (1) having at least one inlet valve (9) and one exhaust valve (11), means for supplying a homogeneous fuel/air mixture to the combustion chamber (3) of the cylinder, and control means (15) for at least varying the degree of opening of the exhaust valve (11), **characterized** in that the control means (15) are so arranged to control the exhaust valve (11) during the exhaust stroke of the piston (4), that the valve, at least within a lower rpm range, closes before the piston has reached its upper dead center point, and that the degree of opening of the valve is varied, depending on the engine load and rpm, so that the amount of residual gases in the combustion chamber at the closing of the valve is greater at low loads and higher rpm than at high loads and lower rpm, to thereby vary the ignition delay by varying the degree of dilution of the fuel/air mixture with residual gases in the combustion chamber.
8. Engine according to claim 7, **characterized** in that the control means (15) are so arranged to control the inlet valve (9) during the inlet stroke of the piston (4), that the valve, at least within said lower rpm range, opens first after a certain number of crankshaft degrees after the upper dead center point of the piston, and that the opening angle is varied in relation to the opening angle of the exhaust

valve, to reduce the residual gas pressure in the combustion chamber to the inlet air pressure.

- 5 9. Engine according to claim 7 or 8, **characterized** in that the valves (9,11) have electromagnetic means (12,13), which are connected to a control unit (15), which controls the valve operating means in response to various signals fed into the control unit.
- 10 10. Engine according to claim 9, **characterized** in that the control unit (15) is connected to an ion stream signal sensor arranged in the combustion chamber (3), a tachometer and a pressure sensor.
- 15 11. Engine according to claim 9, **characterized** in that the control unit (15) is connected to a pressure signal transducer.
- 20 12. Engine according to one of claims 7-12 with an ignition system comprising at least one sparkplug (2) for each cylinder (1) and an ignition control device (14), which is connected to a tachometer and to an accelerator pedal position sensor, **characterized** in that the ignition control device (14) is disposed to keep the sparkplug (2) deactivated within said lower rpm range and to activate the sparkplug when the engine speed exceeds the upper limit of the lower rpm range, and that the control unit (15) of the valves (9,11) is disposed to control the valves within the upper rpm range, so that the inlet valve (9) begins to open before the exhaust valve (11) has completely closed.



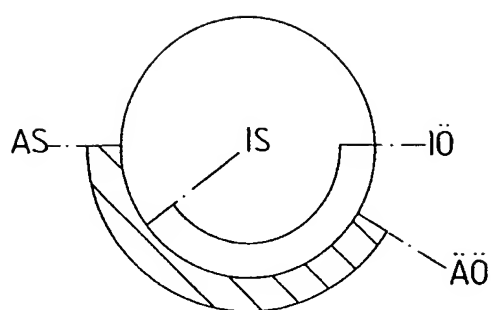


FIG. 5

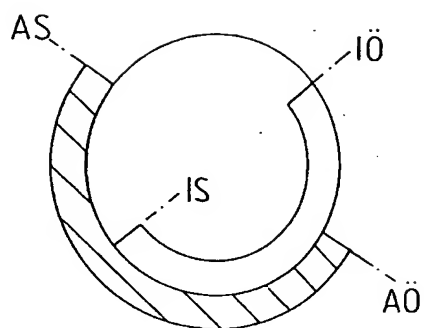


FIG. 6

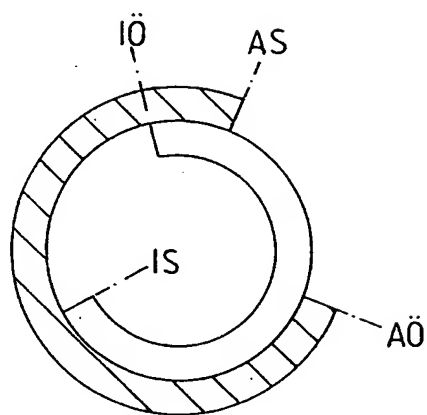


FIG. 7

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 99/01928

## A. CLASSIFICATION OF SUBJECT MATTER

IPC7: F02B 11/00, F01L 9/04, F02D 41/04, F02D 43/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: F02B, F01L, F02D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 9810179 A2 (CUMMINS ENGINE COMPANY, INC.), 12 March 1998 (12.03.98), page 7 - page 10, figure 1, abstract --	
A	EP 0879955 A2 (NISSAN MOTOR COMPANY, LIMITED), 25 November 1998 (25.11.98), figure 1, abstract --	
A	US 4768481 A (A.C. WOOD), 6 Sept 1988 (06.09.88), figures 4,5, abstract --	
A	EP 0367553 A1 (ISUZU MOTORS LIMITED), 9 May 1990 (09.05.90), figures 1,3a,3b, abstract --	

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"I" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

27 January 2000

Date of mailing of the international search report

17 -02- 2000

Name and mailing address of the ISA/

Swedish Patent Office

Box 5055, S-102 42 STOCKHOLM

Facsimile No. +46 8 666 02 86

Authorized officer

Dan Ionesco / JA A

Telephone No. +46 8 782 25 00

# INTERNATIONAL SEARCH REPORT

Information on patent family members

02/12/99

International application No.

PCT/SE 99/01928

Patent document cited in search report			Publication date	Patent family member(s)		Publication date
WO	9810179	A2	12/03/98	AU	4082997 A	26/03/98
				AU	4158097 A	06/03/98
				EP	0928369 A	14/07/99
				WO	9807973 A	26/02/98
-----						
EP	0879955	A2	25/11/98	JP	10318108 A	02/12/98
				JP	10331708 A	15/12/98
-----						
US	4768481	A	06/09/88	JP	1036917 A	07/02/89
-----						
EP	0367553	A1	09/05/90	JP	1912110 C	09/03/95
				JP	2123211 A	10/05/90
				JP	6035812 B	11/05/94
				US	5050543 A	24/09/91
-----						